On the cointegration and causality between Oil market, Nuclear Energy Consumption, and Economic Growth: Evidence from Developed Countries

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Abstract

This study uses Johansen cointegration technique to examine both the equilibrium relationship and the causality between oil consumption, nuclear energy consumption, oil price and economic growth. To do so, four industrialized countries including: the US, Canada, Japan, and France are investigated over the period from 1965 - 2010. The cointegration test results suggest that the proposed variables tend to move together in the long-run in all countries. In addition, the causal linkage between the variables is scrutinized through the exogeneity test. The results point that energy consumption (i.e., oil or nuclear) has either a predictive power for economic growth, or feedback impact with real GDP growth in all countries. The oil consumption is found to have a great effect on economy in all the investigated countries, especially in Canada. Also, exogenous test with respect to the speed of adjustment shows that oil consumption has a predictive power for real GDP in the US, Japan, and France. Regarding nuclear energy consumption - growth nexus, results illustrate that nuclear energy consumption has a predictive power for real economic growth in the US, Canada, and France. On the basis of speed of adjustment, it is concluded that there is bi-directional causality between oil consumption

and economic growth in Canada. On the other hand, there is bidirectional causal relationship between nuclear energy consumption and real GDP growth in Japan.

1 Introduction

In recent years there have been concerns among economists about the relationship between energy consumption and economic growth. Early models such as that of Solow (1956) do not explain how improvements in technology come about, since this model assumes that technological change is exogenous. More recently, the main stream of growth models of Aghion and Howitt (2009) do not include resources or energy. However, many researchers believe that energy plays a crucial role in economic growth as it explains how does the industrial revolution came about (e.g. Wrigley, 1990; Allen, 2009). Furthermore, some authors such as Cleveland et al. (1984), Hall et al. (1986) and Hall et al. (2003) argue that there are two main determinants for the noticeable growth in productivity. They are increase in energy use, and the fact that innovation in technological change mainly increases productivity by allowing the use of more energy. Therefore, high level of energy consumption is an important factor in stimulating economic growth. This fact has triggered interests in identifying the nature of the relationship between energy consumption and economic growth in order to design an effective energy policy that promotes economic growth.

In these efforts, Apergis and Payne (2010a) shed light on the relationship between energy consumption and GDP growth and explain how energy policies and their objectives may affect GDP under four major hypothesis. First, under the growth hypothesis, energy saving policies that reduce energy consumption may have an adverse impact on real GDP.[1] Accordingly, negative energy shocks and energy conservation policies may depress economic growth. Second, the conservation hypothesis proposes that an implementation of a conservation energy policy, would not slow down economic growth. Third, the neutrality hypothesis suggests that energy consumption has little or no impact on GDP; therefore, energy conservation policies do not affect economic growth (Asafu-Adjaye, 2000). Fourth,

[1] This impact is so because the economy is very dependent on energy to grow (Masih and Masih, 1997).

the feedback hypothesis implies that energy consumption and economic growth are jointly determined and affected at the same time. This encourages the implementation of energy expansionary policies for long run sustainable economic growth.

Despite the great significance of a possible relationship between energy consumption and economic growth, there is no consensus yet either on the existence and on the direction of causality between them (Ozturk, 2010). These conflicting results may arise due to different data set, countries' characteristics, variables used, and different econometric methodologies employed (Ozturk, 2010; Menegaki, 2014). The findings from studies vary not only across countries, but depend also on different methodologies within the same country (Soytas and Sari, 2003). Energy consumption variables that are utilised in the existing literature are generally total energy consumption or electricity consumption (Alvarez-Ramirez et al., 2003). However, Sari and Soytas (2004) argue that the use of aggregate energy consumption or electricity consumption, rather than utilising different energy resources, may be another reason behind the inconsistency in the empirical studies' results. It is possible that the importance of a certain energy resource for a country changes over time, which implies that distinguishing the relationship between energy consumption and economic growth based on empirical analysis requires utilising different energy sources rather than using aggregate energy consumption (Sari and Soytas, 2004). The lack of agreement on the direction of causality provides a channel for analysing and discussing the nature of the relationship between energy consumption and economic growth. Vaona (2012) tests for causality between energy use and GDP in Italy using three different approaches, including the Toda and Yamamoto (1995) procedure, the Johansen cointegration test, and the Lütkepohl et al. (2004) cointegration test. In the Vaona (2012) paper, energy has been disaggregated into renewable and non-renewable energy (fossil fuels). The main finding shows that there is a causation relationship between non-renewable energy and GDP, and another relationship from one measure of renewable energy to GDP. However, the standard procedure of the Johansen test does not find cointegration between GDP and fossil fuels at all. Using the approach suggested by Lütkepohl et al. (2004) approach, Vaona (2012) finds cointegration with a structural break.

Based on OPEC's World Oil Outlook 2012, fossil fuels currently account for 87% of the energy demand and will still make up to 82% of the global total energy by 2035. For most of the projection period, oil will remain the energy type with the largest share since it plays a key role in the production process of modern economies. The demand for oil is expected to reach 99.7 mb/d in 2035, rising from 87.4 mb/d in 2011. This demand will be driven mainly by population and economic growth in the emerging economies.[2] However, oil is not only a credible fossil fuel source, it is the major reason for global warming because of the carbon dioxide emission. It also involves risks in terms of security of the supply of energy needs for many energy importing countries, especially because it is concentrated in the unstable region of the Middle East. These reasons have driven the interest among researchers and policy makers to study the linkage between oil consumption and economic growth in both developing and developed countries.

Although oil plays a crucial role in stimulating economic growth as shown above, prices of oil have been exceptionally volatile over the past several years. Historical data show that WTI spot oil prices increased sharply up to $145 in July 2008, and dropped down to a very low level of $30 in December 2008. There are many reasons that support the increase in oil prices rather than its stabilisation. Researchers such as Hamilton (1983, 1988, 1996, 2003), Hooker (1996), and Mork (1989) suggest that the growing demand from developing economies and unrest in many oil-supplying countries of the Middle East and North Africa have caused oil price increases in previous years. During these years, the fluctuations in the prices of oil resulted in many problems that dampened the economy of both oil importing and oil exporting countries. For instance, as oil is an important input in the production process, a rise in the prices of oil follow-on an increase of production costs, which slows down the economic growth of an oil importing country. These effects have been supported through many empirical investigations such as that of Hamilton (2003, 2005), who shows that nine out of ten recessions in the US have been preceded by oil price shocks.

[2]http://www.polsci.chula.ac.th/pitch/ep13/weo12.pdf

From the previous discussion, it can be seen that while there is a rapid increase in international crude oil demand, crude oil prices have suffered from high volatility problem over the last few decades. Therefore, the priority of energy policy for many countries has become diversifying the sources of energy, and finding a stable, safe, and clean energy supply (Toth and Rogner, 2006; Elliott, 2007). As a part of their strategy of increasing energy security, many countries have built nuclear power plants, not only to reduce the dependence on imported oil, but also to increase the supply of a secured energy source and to minimise the price volatility associated with oil imports (Toth and Rogner, 2006).[3] The US Energy Information Administration (EIA) reports of primary energy consumption between 1985 and 2011, show that the considerable growth of electrical consumption in the world requires a massive use of nuclear energy.[4] In 2010, demands for nuclear energy and renewable energy increased due to the limitations of fossil fuels such as oil, natural gas, and coal (de Almeida and Silva, 2009).

Thus, the importance of nuclear power as a potential source of energy, and as a partial replacement for fossil fuels to eliminate emissions creates the need for further research to examine the relationship between nuclear energy consumption and economic growth (Apergis and Payne, 2010b). It is essential to understand the nature of the relationship and identify the direction of causation, to provide logical reasons for investing in nuclear energy for economical concerns or for environmental and social concerns (Chu and Chang, 2012).

To date, few empirical studies have focused on investigating the nature of the relationship between oil consumption and economic growth (see Yoo, 2006; Zou and Chau, 2006; Zhao et al., 2008; Aktaş and Yılmaz, 2008, among others) on the one hand, and between nuclear energy consumption and economic growth on the other (see Yoo and Jung, 2005; Yoo and Ku, 2009; Wolde-Rufael, 2010, among others). There is a dearth of empirical research that looks into the dynamic relationship between oil consumption, nuclear energy

[3]One of the reasons for the shrinking of Japanese oil consumption during the period 1979 - 1985 was the construction of several nuclear power plants for electricity generation. This led to the substitution of crude and fuel oil, and caused a drop in demand of around 1.2 mb/d for the whole period (OPEC's World Oil Outlook 2012).

[4]http://www.eiagov/forecasts/steo/

consumption, oil price, and economic growth using modern advances in time series econometrics associated with causality testing. Given that few studies attempt to examine the causal linkage between the proposed energy consumption variables an economic growth such that of Lee and Chiu (2011a,b) and Naser (2014b,a), the purpose of this paper is to fill this gap by investigating the long run relationship between oil consumption, nuclear energy consumption, oil price, and economic growth using Johansen cointegration analysis.

In particular, this paper runs an investigation among four industrialised countries named; the US, Canada, Japan, and France, over the period from 1965 to 2010. Empirical results provide information about the nature and direction of linkage between nuclear energy consumption and economic growth, oil consumption and economic growth, and oil prices and economic growth. Each country has been examined separately to account for country specific characteristics such as energy patterns and economic crisis. The main reason for studying the long run relationship between oil consumption, nuclear energy consumption and economic growth is that both oil and nuclear energy play an important role in designing effective energy policies that accounts for both economic growth and environmental protection. This also play a vital role in implementing these types of policies.

Results of cointegration analysis illustrates that at least one energy input cannot be excluded from the cointegration space. This implies that a long-run relationship exists between energy consumption and economic growth. As far as the results of cointegration vectors normalised with respect to real GDP growth, the coefficients of oil consumption are found to affect the level of economic growth significantly and positively in the US, Canada, and France. This finding implies that the use of more oil stimulates the real GDP growth. Alternatively, nuclear energy consumption has been found to influence economic growth positively and significantly in Japan, and France. Although oil price is found to be exogenous to the long-run equilibrium error in most countries, it is endogenous and negative in the case of Canada. Furthermore, results from the parsimonious vector equilibrium correction model (PVECM) show that oil consumption has predictive power for economic growth in the US, Japan, and France. Additionally, there is a feedback impact between oil consumption and real GDP growth in Canada. Hence, oil can be considered an important factor to output growth in this country. Regarding the nuclear energy consumption - growth nexus, there is a bi-directional relationship between nuclear energy consumption and output growth in Japan. Moreover, nuclear energy consumption is found to have information that could predict real GDP growth in the US, Canada, and France.

In what follows, background and a literature review are provided in Section 2. Section 3 describes the econometric methodology. Section 4 illustrates the data sources and definitions of the variables. Section 5 shows the empirical results, and a conclusion is provided in Section 6.

2 Literature Review

2.1 Oil Price and Economic Growth

With a glance at oil market report published in the Organization for Economic Cooperation and Development (OECD) and the International Energy Agency (IEA, 2012) in 2012, it is clear that oil is still representing a dominant form of energy source due to its flexibility and worldwide strength. Therefore, the impact of crude oil prices received a high attention from many researchers since the 1970s. As suggested by Doğrul and Soytas (2010), increases in oil prices lead to increases in the cost of production in many sectors; this might reduce production and increase unemployment while also resulting in inflation. Importantly also, increases in oil prices erode export competitiveness. This is even more critical if an economy is dependent on importing raw materials and intermediate goods.

In theoretical studies, the relation between oil price and economic growth has been widely investigated and several transmission channels of the variations of oil price to economic growth have been identified (Bruno and Sachs, 1982; Pierce et al., 1974). In this context, economists have initially focused on the most basic channel named; the classic supply-side effect, which suggests that rising oil prices are indicative of the reduced availability of a basic input to production, leading to a reduction in the overall potential output (see Abel and Bernanke, 2001; Brown and Yuecal, 1999, among others). Accordingly, if the cost of production increases, growth of the output and productivity will slow down. Second, the transfer of income from oil-importing countries to oil-exporting countries leads to a fall in the purchasing power of firms and households in oil-importing countries (Dohner, 1981; Fried et al., 1975). Third, a rise in oil price would drive an increase in money demand based on real balance effect, as proposed by Pierce et al. (1974) and Mork (1994). Then, a failure of the monetary authority to meet growing money demand with increased supply would boost interest rates and retard economic growth (see Brown and Yücel, 2002, for more details).[5] Fourth, as consumption is positively linked with disposable income, oil price increase may have a negative impact on consumption. Also, this increase in oil prices may affect investment negatively by increasing firms' costs. Fifth, a long-lasting increase in oil price would change the production structure and, accordingly, affect the level of unemployment.[6] Indeed, a rise in oil prices may encourage firms to adapt and construct new production methods that are less intensive in oil inputs. This change generates capital and labour reallocations across sectors that can affect unemployment in the long run (Loungani, 1986). In addition, an increase in oil price generates inflationary pressures, which is accompanied by direct and indirect effects (see Álvarez et al., 2011, for more details). Neither the real balance effect nor monetary policy can alone yield both slowing GDP growth and an increase in inflationary pressure (Brown and Yücel, 2002).

However, empirical investigations have generally started with regressing GDP on oil prices and several other variables (Rasche and Tatom, 1977a,b) to analyse the impact and the magnitude of oil price effects on aggregate economic activity. In particular, Hamilton (1983) has utilised Granger causality test to scrutinise the impact of oil price shocks on the US economy between 1949 - 1972. He shows that when oil prices are determined exogenously, oil price fluctuations Granger-cause changes in GNP and unemployment. Gisser and Goodwin (1986) reinforced Hamilton's findings for the US by examining the

[5] Bohi (1989, 1991) and Bernanke et al. (1997) argue that confectionary monetary policy accounts for much of the decline in aggregate economic activity following an oil price increase.

[6] In a recent study, Doğrul and Soytas (2010) find that the real price of oil and interest rates in Turkey improve the forecasts of unemployment in the long run.

impact of oil price shocks on some macroeconomic variables in the US. Burbidge and Harrison (1984) have also found supporting evidences from the US, Canada, UK, Japan and Germany. Using VAR models, Burbidge and Harrison (1984) show that the 1973 - 1974 oil embargo explains a substantial part of the behavior of industrial production in examined country. Jiménez-Rodríguez and Sánchez (2005) find that oil price movement has asymmetric impact on GDP growth in major industrialised countries. Notably, oil price upsurges are found to have an impact on GDP growth of a larger magnitude than that of oil price declines, with the latter being statistically insignificant in most cases. Among oil importing countries, oil price increases are found to have a negative impact on economic activity in all cases but Japan. Moreover, the effect of oil shocks on GDP growth differs between the two oil exporting countries in the sample, with the UK being negatively affected by an oil price increase and Norway benefiting from it. Álvarez et al. (2011) find that the changes in crude oil prices have both direct and indirect impacts on Spain and Euro zone economic growth. In addition, they find evidence that crude oil prices play a vital role in determining inflation. In contrast, Mehrara and Mohaghegh (2011) find that oil price movements are not necessary inflationary. Yet, the results of the panel VAR model show that changes in oil price yield a significant effect on economic growth and a positive and significant effect on money supply.

2.2 Energy Consumption and Economic Growth

Energy economists underlined that energy is a major driving force in wealth creation (Stern, 2011). This is so because it plays a considerable role in output production and accordingly influence the overall level of economic growth (Beaudreau, 2005; Stern and Cleveland, 2004). It has also a significant role in determining the income as stated by the ecological vision. This implies that the economies that are highly dependent on energy use will be notably subjective by the deviation in energy consumption (Cleveland et al., 1984). In addition, the historical data indicate that there is a strong relationship between the availability of energy, economic progression, and enhancements in standards of living and in general social well-being (Nathwani et al., 1992). Therefore, assessing the impact of energy consumption on economic growth empirically has become the focus of many researchers. Most of theoretical and empirical literature have point out that the size of energy that contribute to productivity developments and economic growth has been greatly underestimated (Sorrell, 2010).

Since the seminal article of Kraft and Kraft (1978), a number of studies have attempt to investigate the causal relationship between energy consumption and economic growth in both developed and developing countries. However, to date empirical results are conflicting. For instance Kraft and Kraft (1978) show that there is a unidirectional causality running from real GNP to energy consumption in the US, on one hand, where the investigation has been implemented using annual data that covers the period from 1947 to 1974. On the other hand, Akarca and Long (1980) replicate the work by excluding the years 1973 - 1974 from the sample and argue that the causal order suggested by Kraft and Kraft (1978) is spurious and is sensitive to the sample period due to temporal sample instability.

In a bivariate framework, Yu and Hwang (1984) apply both the causality test projected by Sims (1972) and Granger (1969) for the extended USA annual data from 1947 to 1979. In line with Akarca and Long (1980), they discover that there is no causal relationship between GNP and energy consumption in the US. However, the same authors replicated the work using quarterly data and demonstrate that there is a unidirectional causality running from income to energy consumption from 1973 to 1981. These tests have been applied to a number of other industrialised countries to study the causal relationship between energy consumption and economic growth. Findings from the above exercises show that there is causation between energy and output (Yu and Choi, 1985; Erol and Yu, 1987). Yu and Jin (1992) expand the work to examine whether energy consumption and output are cointegrated in the long-run for the US data. They find that energy consumption is not cointegrated with income and employment. More recently, using the cointegration analysis proposed by Johansen and Juselius (1990), Soytas and Sari (2003) test the causal linkage between real GDP and energy consumption in ten emerging economies and G7 countries. They find that there is a long run unidirectional causality running from energy consumption to real GDP for Turkey, France, West Germany and Japan, while the reverse causality exists for Italy and Korea. However, they could not find a long-run relationship between energy consumption and real GDP in the US. Zachariadis (2007) examine the effectiveness of the bivariate framework using three different time series approaches including VECM, ARDL, and the Toda and Yamamoto (1995) model. The sample used in his study cover a number of industrialised countries including Canada, France, Germany, Italy, Japan, the UK, and the US. He uses two different types of data including the total and the sectoral data. Zachariadis (2007) finds that Japans' data exhibits a cointegrating relationship for all energy-economy pairs. He shows that there is no evidence for causality at the level of the total economy, while for services as well as transport sectors, GDP Granger causes energy consumption.

Although bi-variate approaches utilized in early studies are attractive due to the fact that they can be used for developing countries which suffer from a shortage of complete data on some variables of interest, deriving policy implications from these models should be done carefully (Zachariadis, 2007).[7] Zachariadis (2007) illustrates that using large sample size and multivariate models are more realistic and closer to economic theory as well as accommodating several methods. Thus, recent papers employ either a trivariate or multivariate time series framework when examining energy-growth nexus to overcome the weakness of omitting variables problem in bivariate approaches. The basic idea of these papers implies that capital, labour, and technological change are key factors in determining output. Nevertheless, early studies completely assume that the only input in production is energy, which might lead to omitted variables bias if this assumption is not true. Moreover, one can end up with spurious regression results if the investigation includes stochastically trending variables (Stern and Common, 2001).

Using a multivariate framework, Stern (1993) employs a VAR model that consists GDP, capital, labour inputs, and energy consumption represented by Divisia index measured in heat units.[8] In this set up, he tests for Granger causality and finds that energy

[7] Payne (2010) notes that a large body in the literature (26 of 35 studies surveyed) employ bivariate models, which might suffer from omitted variables bias.

[8] Divisia index is a method of aggregation used in economics that allows variable substitution in material types without imposing a priori restrictions on the degree of substitution.

Granger causes GDP. Stern (2000) extends the work applied in Stern (1993) by estimating a cointegrating VAR for the same variables. The investigation shows that there is a cointegrating relationship that link the four variables proposed. Also he finds evidence that support the existence of a unidirectional causality flowing from energy to GDP. Warr and Ayres (2010) repeat the same model to examine energy-growth nexus in the US. They have used another approximation for energy use and useful work.[9] The key findings reveal that there are unidirectional causalities running from whichever energy or useful work to economic growth in both short and long run. Following these credible results, the methodology of Stern (1993, 2000) has been used to examine the relationship between energy consumption and economic growth for many countries. For instance, Oh and Lee (2004) use it for Korea, while Ghali and El-Sakka (2004) use it for Canada. Using the Johansen cointegration technique, Ghali and El-Sakka (2004) indicate that the long-run movements of the proposed variables in Canada are related by two cointegrating vectors. However, Oh and Lee (2004) show that there is only one cointegrating vector for Korea. In respect to causality testing, both studies obtain exactly the same conclusion as Stern's investigation for the US. Using an alternative approach proposed by Toda and Yamamoto (1995), Bowden and Payne (2009) demonstrate that the relationship between energy consumption and real GDP is not uniform across sectors in the US. They propose that the policies of energy and environment should take into accounts that the sectors in general vary in the nature of the relationship between energy consumption and real GDP.

Some studies attempt to analyse the relationship between energy consumption and economic growth using panel data. For example, Lee and Chang (2008) and Lee et al. (2008) exploit the information from panel data and apply cointegration techniques to investigate the relationship between GDP, energy consumption, and capital in 16 Asian and 22 OECD countries, respectively. Lee and Chang (2008) show evidence that of causality running from energy to GDP in the long run for the investigated Asian countries, while Lee et al. (2008) propose the existence of a bi-directional relationship between energy consumption and GDP in the OECD sample. Similarly, Apergis and Payne (2009) em-

[9]'Useful work' is a measure that captures energy flow and energy efficiency effects.

ploy panel cointegration and panel causality tests for six Central American countries and find evidence of the growth hypothesis for the period 1980 - 2004. Jointly, results so far propose that the uncertain findings of those early studies are perhaps consequences to neglecting the role of other non-energy inputs. Oppositely, the studies that use panel data into bivariate methods such as Joyeux and Ripple (2011) test energy-growth nexus in 56 countries including developed and developing economies. They find that there is a unidirectional causality flowing from income to energy use. Chontanawat et al. (2008) employ panel data that covers 100 countries in order to investigate the causation between energy use and GDP. They denote that the potential of predicting GDP using the information content of energy use in developed OECD countries are more ordinary in comparison to the developing non-OECD countries.

Many researchers argue that if the estimated model does not account for other possible determinants such as that of energy prices, then results may be biased. For example, Glasure (2002) indicates that the real oil price is a major determinant of real national income and energy consumption. Hence, literature has included oil prices in many studies including panel data studies as an additional explanatory variable in energy growth models. A remarkable example is provided by Costantini and Martini (2010) for 26 OECD countries from year 1978 to year 2005. They employ panel data into vector error correction model (VECM) using economic growth, energy consumption, and prices of energy. The results show that there is a unidirectional causality from energy prices to GDP and energy consumption in the short-run, and that energy consumption and GDP are having a feedback effect. However, they discover that stimulating economic growth needs more energy in the long-run and thus affect the level of energy prices. Despite the fact that studies which focus on individual countries have commonly modeled the long-run relationship between economic growth, the use of energy, and the prices of energy, the results produced are mixed. For example, although conclusions drawn by Glasure (2002) and Costantini and Martini (2010) are very similar in the case of Korea, Masih and Masih (1997) and Hondroyiannis et al. (2002) show that Korea and Taiwan, respectively are having feedback effect between energy consumption and economic growth in the long-run.

Although econometric methods applied in literature witnessed a wide diversification, a clear conclusion on the role of energy consumption in enhancing economic growth or employments has not been achieved yet. The diversifications of methodologies used in researches have not only influenced the results across countries, results within the same country have also been mixed (Soytas and Sari, 2003). Moreover, Yang (2000) proposes that the pattern of energy consumption may differ over time. Looking at the aggregated energy consumption would accordingly ignore the change in the importance of different energy sources through time. Therefore, the performed studies end up with different results over different periods of time even for the same country. For instance, Yang (2000) finds a feedback impact between aggregate energy consumption and GDP in Taiwan. However, when energy consumption is disaggregated into coal, oil, natural gas, and electricity, he observes different directions of causality, which underlines the importance of analysing the relationship between different sources of energy consumption and GDP.

For this purpose, Zou and Chau (2006) have focused on examining both the information contents and the long-run relationship between oil consumption and economic growth in China. Using cointegration and Granger causality tests, the key finding reveals that the above variables are co- integrated and oil consumption contains information that help to forecast movements in the economy in both short run and long run. Given that the investigation results provide evidence on the significant role of oil consumption in developing the economy, sectors like the industry may directly yield a growth in economy by increasing the use of oil. However, this should be considered with care due to many environmental issues. Conversely, they find that economic growth has information that can predict oil consumption only in the long run. Based on Chinas' energy structure, Zou and Chau (2006) show that economic development has a minor impact on the level of oil consumption. Using modern time-series techniques, Yoo (2006) attempts to examine both short- and long-run causality between oil consumption and economic growth in Korea. In his study, he employs annual data over the period from 1968 to 2002 into an error-correction model. The key finding from this investigation is that oil consumption and economic growth have a feedback effect in Korea, which means that economic growth is encouraged by using more oil and additional oil use is also needed to accommodate the energy demand associated with economic growth. Lee and Chang (2005) scrutinise the stability between energy consumption and GDP in Taiwan during the period of 1954 - 2003. They exploit the information from aggregate in addition to various disaggregated measures of the consumption of energy, including coal, oil, gas, and electricity. Then cointegration tests that accounts for structural breaks are employed. The key finding is that the directions of causation between GDP and the use of different energy resources are mixed. They point out that there are feedback effects between GDP and both overall energy and coal consumption. However, there is a unidirectional causality running from oil consumption to economic growth. Additionally, unidirectional causalities flowing from gas and electricity use to economic growth are discovered. Another recent article developed by Ziramba (2015) assesses the long-run and causal relationships between oil consumption and economic growth in South Africa over the period 1970 - 2008. Using multivariate framework, he finds that capital, oil consumption, and economic growth have a stable long-run relationship. Also, he finds that there is a unidirectional causality from oil consumption to economic growth, which implies that oil consumption play a vital role in stimulating economic growth both directly and indirectly as a complement to other inputs in the production process. Park and Yoo (2014) have used annual data covering the period 1965-2011 for Malaysia to examine the linkage between oil consumption and economic growth. On the basis of the cointegration approach results, they find that the two variables have feedback impacts on each other. This means that an increase in oil consumption directly affects economic growth, and an increase in economic growth need more oil usage as well. Thus, in order not avoid any adverse impacts on economic growth in Malaysia, energy policies should endeavor to overcome the constraints on oil consumption.

From the above discussion, it is clear that there is always growth in the demand for oil, which accordingly increases green house gases (GHG) emissions. Under the vision of sustainable development, many countries agreed on conserving energy and reducing CO2 emissions associated with burning so much fossil fuel. Therefore, researchers have become more interested in analysing the impacts of nuclear and renewable energy consumption on economic growth. Many researchers believe that nuclear energy is a nearly carbon-free source of energy that can eliminate the global warming problem and provide a reasonable energy source (Elliott, 2007; Ferguson, 2007).

Early studies such as that of Yoo and Jung (2005) find a unidirectional causality running from nuclear energy consumption to economic growth without any feedback impact in Korea. Yoo and Ku (2009) examine the long-run relationship between nuclear energy consumption and economic growth in 20 countries using time-series data, however; the Granger causality test has been implemented for only six countries. They find that there is a unidirectional causality from energy consumption to economic growth in South Korea, while opposite causalities are found in France, and Pakistan. Furthermore, bidirectional causality has been found in Switzerland, and no causation is detected in neither Argentina nor Germany. Wolde-Rufael and Menyah (2010) find mixed results from investigating nuclear consumption -economic growth nexus in nine industrialised countries. Their results put forward the lack of causality for the US and France, while energy use stimulates economic growth in Japan, the Netherlands, and Switzerland. In addition, they find feedback effect in France, Spain, the UK and the US. Lee and Chiu (2011a) find that using more energy causes economic growth Japan, and feedback effect in Canada, Germany and the UK. Heo et al. (2011) use the cointegration and error-correction models for India. They conclude that there is a unidirectional causality running from nuclear energy consumption to economic growth. Use panel data, Apergis et al. (2010) show that there is bidirectional causality between nuclear energy consumption and economic growth.

To date, few empirical studies have focused on investigating the relationship between oil consumption and economic growth, on the one hand, and between nuclear energy consumption and economic growth on the other (Yang, 2000; Zou and Chau, 2006; Zhao et al., 2008; Aktaş and Yılmaz, 2008; Yoo and Jung, 2005; Yoo and Ku, 2009). Although oil prices are found to have a significant impact on oil consumption, demand for nuclear energy and macroeconomic activities, have been neglected in most energy consumption - economic growth investigations. Observing that minor attention has been given in the literature to tackle the interaction between oil and a new clean energy source (nuclear energy) and taking into consideration the vital role of fluctuations in oil prices (Lee and Chiu, 2011a,b; Naser, 2014b,a), this paper attempt to link two literature streams and employ the parsimonious vector equilibrium correction model (PVECM). The primary aim of this study is to analyse the long-run relationship between oil consumption, nuclear energy consumption, oil price and economic growth. Additionally, causality relationship between the proposed variables and output growth are examined.

3 Econometric Methodology

The objectives of this empirical study are to examine how the variables (i.e., GDP, oil and nuclear energy consumption, and oil prices) are related in the long-run and to assess the long-run causal relationship between these variables. In line with these objectives, cointegration technique is applied to examine the long-run relationship(s) in each country. It is worth noting that early cointegration techniques pioneered by Engle and Granger (1987), Hendry (1986), and Granger (1986) have made a significant contribution towards cointegration and long-run relationship(s) analysis and causality testing between time series variables. Thus, these techniques have become popular both as a topic for theoretical investigation of statistical issues and as a framework within which many empirical propositions can be re-evaluated (Perron and Campbell, 1994). The basic idea the cointegration, in general, suggests that two or more variables are said to be cointegrated, that is they exhibit long-run equilibrium relationship(s), if they share common trend(s). More concretely, Engle and Granger (1987) demonstrate that once a number of variables are found to be cointegrated, there always exists a corresponding error-correction representation that denotes that changes in the dependent variable are a function of the level of disequilibrium in the cointegrating relationship (captured by the error-correction term) as well as changes in other explanatory variable(s).

In this setup, a method of estimation and testing that has received a particular attention is the maximum likelihood approach based on a finite VAR Gussian system developed by Johansen (1991).[10] This technique has several advantages over the Engle and Granger (1987) approach.[11] For instance, Johansen and Juselius method tests for all the number of distinct cointegrating vectors between the variables in a multivariate setting and estimates the parameters of these cointegrating relationships. All the tests are based on the trace statistics test and the maximum eigenvalue test. It also treats all variables as endogenous, thus avoiding any arbitrary choice of dependent variable. Moreover, this technique provides a unified framework for testing and estimating relationships within the framework of a vector error correction mode (VECM) (Enders, 2008). According to this technique, evidence of cointegration rules out the possibility of the estimated relationship(s) being 'spurious'. Also, as long as the variables included in the cointegration space have common trend, causality; in the Granger sense must exist in at least one direction either unidirectional or bidirectional (Granger, 1986, 1988).[12]

Since the focus of this paper is to investigate the relationship between energy consumption (oil and nuclear energy) and economic growth and to assess the causal linkage between them, whose analysis requires estimation techniques appropriate for long-run equilibria, the Johansen test (Johansen, 1988; Johansen and Juselius, 1990; Johansen, 1991) is used as discussed below.[13]

3.1 Cointegration Modeling

Assume that Z_t is a vector including integrated series at the same order, which have at least one cointegrating vector in the system. A general-to-specific approach is adopted to model both the long-run and short-run structure of vector Z_t .

First, the Johansen Maximum Likelihood approach is employed to estimate and iden-

[10] For description of the procedure and detailed empirical applications, see Johansen (1988), Johansen (1989), and Johansen and Juselius (1990).

[11] Engle and Granger (1987) indicate that the statistical inference for a VAR in levels can be undertaken appropriately only if all the variables are stationary. Otherwise, one can use VAR in differences if all the variables are integrated of order one but are not cointegrated, and through the specification of a vector error correction model (VECM) if all variables are integrated of order one and cointegrated.

[12] Failure to reject the null hypothesis that x does not cause y, does not necessarily mean that there is in fact no causality. A lack of sensitivity could be due to a misspecified lag length, insufficiently frequent observations (Granger, 1988), too small a sample (Wilde, 2012), omitted variables bias (Lütkepohl, 1982), or nonlinearity (Sugihara et al., 2012).

[13] Although there exists a number of co-integration tests, such as the Engle and Granger (1987) method and the Stock and Watson (1988), Johansen's test has a number of desirable properties as shown above.

tify the cointegrating relationships among the variables included in vector Z_t . More concretely, Z_t can be written as a vector autoregressive process of order k (i.e., VAR(k)):

$$Z_t = A_0 + \sum_{i=1}^{k} A_i Z_{t-i} + u_t \tag{1}$$

$$\Delta Z_t = A_0 + \Pi Z_{t-1} + \sum_{i=1}^{k} \Gamma_i \Delta Z_{t-i} + u_t \tag{2}$$

$$\Delta Z_t = A_0 + \alpha\beta' Z_{t-1} + \sum_{i=1}^{p} \Gamma_i \Delta Z_{t-i} + u_t, \qquad u_t \text{ is } iid \sim N(0, \Sigma) \tag{3}$$

Where Z_t denotes (4×1) vector containing GDP, oil consumption, nuclear energy consumption, and oil prices (i.e., $Z_t = (RGDP_t, OC_t, NC_t, ROP_t)$). The four variables are measured by their natural logarithm so that their first difference approximate their growth rates. Any long-run relationship(s) are captured by the (4×4) matrix Π shown in equation (2). However, this matrix can be decomposed as shown in equation (3) to provide better understanding for the full system, where β is the $(4 \times r)$ matrix of the cointegrating vector and α denotes the $(4 \times r)$ matrix of speed of adjustment to last period equilibrium error. Γ_i represents (4×4) matrices that guide short run dynamics of the model.

In the second step, the vector equilibrium correction models presented by equation (3) are estimated, where the identified matrix of cointegrating vectors β is explicitly taken into account:

$$\Delta Z_t = \hat{A}_0 + \hat{\alpha}(\sum_{i=1}^{r} \hat{\beta}_i{}' Z_{t-1}) + \sum_{i=1}^{p} \hat{\Gamma}_i \Delta Z_{t-i} + u_t \tag{4}$$

At this stage, equation (4) is re-estimated by excluding any insignificant regressors. The resulting parsimonious vector equilibrium correction model (PVECM) is a reduced form model and consequently, there are simultaneity effects among the endogenous variables including in Z_t. Having estimated the PVECM, the causal linkage between the variables are examined through exogeneity test, which test aginst the null α_i is not significantly different from zero ($i.e.$, $H_0 : \alpha_i = 0$). If the null is true then the variables included z_i is exogenous with respect to all cointegrating vectors.

In the third step, the estimated model can be represented by equation (4), which is conditional on exogenous variables.

$$\Delta Z_{1,t} = \hat{A}_0 + \Delta Z_{2,t} + \hat{\alpha}(\sum_{i=1}^{r} \hat{\beta}_i{}' Z_{t-1}) + \sum_{i=1}^{p} \hat{\Gamma}_i \Delta Z_{t-i} + u_t, \qquad u_t \text{ is } iid \sim N(0, \Sigma_1) \quad (5)$$

where $\hat{\alpha} = [\alpha_1, 0]'$, and Z_2 is the vector of exogenous variables.

In the fourth step, simultaneous effects are modeled as shown in equation (5). If any of the off diagonal elements of Σ_1 is close to zero, OLS is applied to estimate each equation of the system shown in (5) separately.

4 Data Source and Description

The yearly data-set used in this paper cover the period from 1965 to 2010 for four developed countries, including the US, Canada, Japan, and France. The set of variables in this study are time-series variables that include nuclear energy consumption per capita (NC), real oil prices (ROP), oil consumption per capita (OC) and real GDP per capita (RGDP). Oil consumption is the sum of inland demand, international aviation, marine bunkers, oil products consumed in the refining process, and consumption of fuel ethanol and biodiesel. Both Nuclear energy and oil consumption are obtained from BP Statistical Review of World Energy (2011) where NC is expressed in terms of Terawatt-hours (TWh) and OC is measured in thousand barrels daily. Oil consumption (OC) is the sum of inland demand, international aviation, marine bunkers, oil products consumed in the refining process, and consumption of fuel ethanol and biodiesel. Real GDP per capita measured based on purchasing-power-parity (PPP) per capita in constant 2000 international dollars from the World Development Indicators (WDI, 2011). Real oil price is defined as the US dollar prices of oil converted to the domestic currency and then deflated by the domestic consumer price index (CPI), which is derived from International

Financial Statistics (IFS, 2009) published by the International Monetary Fund (IMF). All data are expressed in natural logarithms in the empirical analysis.

The empirical investigation started by plotting the variables of each country to analyse the general behavior of them, then the descriptive statistics for the proposed variables across all countries are provided in Table (1) below. The descriptive statistics are calculated to find the mean, standard deviation, minimum, maximum, skewness, kurtosis and Jarque-Bera statistic for normality for each variable included in the analysis. With a glance at the results shown in Table (1), it is clear that the highest mean real GDP is observed in Japan followed by the US, Canada, and France during the sample period (1965 - 2010). The US has the mean highest oil consumption and nuclear energy consumption among the other countries. Majority of variables have negative skewness values, which denote that the distribution of the data is skewed to the left. However, results obtained from Jarque- Bera test show that real oil price, oil consumption, and real GDP exhibit normal distribution, while nuclear energy consumption seem to be characterised by a non-normal distribution.

5 Empirical Work and Results

In order to avoid any spurious regression, variables need to be examined carefully (Clarke and Mirza, 2006). Therefore, this paper started to investigate the order of integration of each variable, I_d, by applying different unit root tests including: the augmented Dickey and Fuller (1979) (ADF), Phillips and Perron (1988) (PP), and the stationarity test by Kwiatkowski et al. (1992) (KPSS).[14] This in general make comparing results from different alternative tests more likely to provide the opportunity to examine whether the preponderance of the evidence makes a convincing case for stationarity or non-stationarity. Table (2) shown below reveals that the obtained results are slightly contradictory. However, all variables are roughly non stationary at level and integrated of order one- I(1).

Then, determining the optimal lag number is another important preliminary test.

[14]Using different unit root tests is an important exercise to account for the controversies surrounding the unit root testing as proposed by Maddala and Kim (1998).

Thus, Akaike (AIC), Hannan and Quinn (HQIC), and Schwarz's Bayesian (SIC) information criteria are used to build a decision with regards to the optimal number of lag length, k.[15] Here, Lütkepohl (1993) approach is followed by linking the maximum lag lengths ($kmax$) and the number of endogenous variables in the system (m) to the sample size (T) according to the following formula: $m * kmax = T^{\frac{1}{3}}$ (Konya, 2004). Following Pesaran and Pesaran (1997), the best number of lags are chosen on the basis of AIC in the case of conflicting results of the different Information criterion. Table (3) shows the results of lag selection criteria for each country.

For further investigations, diagnostic tests including normality and autocorrelation have been employed. Based on Lagrange-multiplier (LM) test for autocorrelation shown in Table (4) below, the null hypothesis of no autocorrelation in the residuals cannot be rejected for any of the orders tested at 5% level. Also, all models pass the normality test at 10% level or better, which indicate that there is no evidence of model misspesification in our models.

Then, the cointegration vectors are estimated using the reduced-rank approach suggested by Johansen (1988); Johansen and Juselius (1990). For this purpose, CATs in RATs has been used to examine the long-run relationship between oil consumption, nuclear energy consumption, oil price and economic growth. Thus, Johansen (1988) test has been employed in order to test for the existence of $r \leq 3$ cointegration relationships among the four variables of the model. This is equivalent to testing the hypothesis that the rank of matrix Π in Equation (2) is at most r. Reduced-rank regression can then be used to form a likelihood ratio test of that hypothesis on the basis of the so-called trace statistic, or alternatively, the maximum eigenvalue statistic. Lüutkepohl et al. (2001) investigate the small sample properties of both tests and concluded that the trace test is slightly superior, and therefore, it is favored it in this analysis. The results of testing for the number of cointegrating vectors are reported in Table (5), which presents both the maximum eigenvalue (λ_{max}) and the trace statistics. Results of trace statics in the fifth column of Table (5) show that the null hypothesis of no cointegration can be rejected at

[15]It is worth to note that if the chosen lag is less than the true lag length, this can cause bias due to omission of relevant lags the cointegration analysis.

1% and 5% significance level, except for Canada.[16] These findings suggest the existence of one cointegration vector in each country model. Hence, a cointegration rank of one is imposed on the VAR and the coefficients are estimated using Equation (3) as shown in Table (6).

However, from the β vectors presented in Table (6), it is clear that there are some insignificant coefficients of different variables in the cointegration space of each country model. Accordingly, following Johansen (1996), an exclusion test that examine whether or not a variable can be excluded from a contigration space is utilized for for all variables in each country model. Particularly, this test uses zero restriction on β to identify the long-run relationship. Results provided in Table (7) shown below reveal that the US exclusion tests of nuclear energy consumption and real oil price yield likelihood ratio test of 0.943, and 0.084, respectively. This enable us to easily accept the null hypothesis and therefore, exclude these two variables from the US cointegration space. Following the same method, nuclear energy consumption is excluded from the cointegrating vector of Canada as the statistics show a likelihood ratio of 0.276. In Japan, findings support that the cointegration vector is clearly identified by excluding both oil consumption and real oil price. Results of likelihood ratio test for France provided in the third column of Table (7) report that the null hypothesis of $H_0 : \beta = 0$ is rejected for all the proposed variables, except for real oil price, which denotes that real GDP, oil and nuclear energy consumption determine the long-run linkage significantly.

After excluding the insignificant variables from the cointgration space, weak exogeneity is investigated against the null hypothesis $H_0 : \alpha = 0$, as proposed by Johansen (1992, 1996). A rejection of the null hypothesis means that there is evidence of unidirectional long run causality (Arestis et al., 2001; Hall and Wickens, 1993; Hall and Milne, 1994).[17] With a glance at the results reported in Table (8), It is clear that oil consumption is

[16] In Canada, we reject the null hypothesis of no-cointegration at 10% level.

[17] Following Hall and Wickens (1993) and Hall and Milne (1994) explain how weak exogeneity can be interpreted as a long-rn causality in details. They have shown that for example, if we consider the economic growth equation as following: $\Delta GDP_t = \hat{A}_0 + \hat{\alpha}_{11} ECT_{t-1} + \hat{\gamma}_{11} \Delta GDP_{t-1} + \hat{\gamma}_{12} \Delta OC_{t-1} + \hat{\gamma}_{13} \Delta NC_{t-1} + \hat{\gamma}_{14} \Delta ROP_{t-1}$, where $ECT_{t-1} = \hat{\beta}_{11} GDP_{t-1} + \hat{\beta}_{12} OC_{t-1} + \hat{\beta}_{13} NC_{t-1} + \hat{\beta}_{14} ROP_{t-1}$ is the error correction term, i.e. the cointegration relationship between the variables. Then restricting $\hat{\alpha}_{11} = 0$ is a test for weak exogeneity where rejection of the null hypothesis means there is evidence of long run causality going from the variables in the ECT to GDP.

exogenous in three out of four countries including the US, Japan, and France, with test statistics of 0.361, 0.366, and 0.248, respectively. This implies that oil consumption has a predictive power to economic growth in these countries, which is in line with Lee and Chiu (2011a) outcomes for France, the UK, and the US. However, it is contradicting with Lee and Chiu (2011b) results, who use panel data-set in their analysis. They find that there is an opposite causality running from real income to oil consumption in the short-run, implying that an increase in real income may lead to the demands for oil in the short run, and that the policies for reducing oil consumption may not retard economic growth. On the other hand, nuclear energy consumption cannot reject the null hypothesis of weak exogeneity in both the US and Canada, with likelihood ratios of 3.155 and 0.692, respectively, suggesting a unidirectional causal linkage running from nuclear energy consumption to economic growth. Thus, a high level of nuclear power consumption leads to high level of real economic growth in the US and Canada. These results support the the findings of the long-run causality from nuclear energy consumption to economic growth for Korea by Yoo and Jung (2005) and Yoo and Ku (2009), Wolde-Rufael and Menyah (2010) for Japan, Apergis and Payne (2010b) for panel data of 16 countries, and Wolde-Rufael (2010) and Heo et al. (2011) for India. Yet, it is conflicting with Yoo and Ku (2009) for France and Pakistan, and Wolde-Rufael and Menyah (2010) for Canada and Switzerland.[18] With respect to oil price exogeneity test, Table (8) indicate that there is a unidirectional causal relationship from real oil price to economic growth in both Japan and France.

Then, the model is re-estimated at this point using the parsimonious vector equilibrium correction model (PVECM) shown in Equation (4). The results of β and α estimates are based on the above exclusion and weak exogeneity restrictions for the investigated countries. Since all variables are in natural logarithms, the estimated long-run coefficients can be interpreted as elasticities. In the US, it is observed that the long run oil consumption elasticity of economic growth is 0.759, which is positive and statistically significant at 1% level. This suggest that increasing oil consumption by 1%, increases the real GDP growth

[18] Payne and Taylor (2010) also find different results as they show that there is no causal relationship between nuclear energy consumption and economic growth in the US.

by 0.759% in the US. The coefficient on the time trend component can be interpreted as a measuring for the rate of technical change in the US The estimated rate of technical change is 0.12%, which is close to that estimated by Stern (2000).

In the case of Canada, it can be seen from the estimated long run relationship that oil consumption has a positive and high significant impact on economic growth, while output is negatively linked with oil price.[19] An increase of 1% in oil consumption increases the growth by 3.1% approximately. In contrast, increasing oil price by 1% decreases the growth in Canada by 0.499 %.

Alternatively, the long run nuclear energy consumption elasticity to economic growth in Japan shows that an increase of 1% in nuclear energy consumption increases the real GDP by 0.108 %. Lee and Chiu (2011a) find that nuclear energy demand is elastic with respect to real income in Japan, and a 1% rise in real income raises nuclear energy consumption with a 1.436 %. They suggest that countries with higher income levels are more likely to have their basic needs and are concerned with environmental problems, since they have more money to invest in nuclear energy development. Thus, for highly industrialised countries, economic development leads to higher nuclear energy demand (Lee and Chiu, 2011a).[20] The estimated technological change impact on GDP growth is 0.12% for every 1% increase.

In France, the long run relationship includes both energy sources (oil and nuclear power), trend and economic growth. These findings suggest that the process of economic development in France is heavily dependent on both oil and nuclear energy consumption, and the rate of technical change. An increase of 1% in oil consumption increases the real GDP by 0.262%, and an increase of 1% in nuclear energy consumption increases the real GDP by 0.049%. The coefficient on the time trend component reveals that the rate of

[19]Canadas' economy is relatively energy-intensive when compared to other industrialized countries, and is largely fueled by Petroleum, which represents the highest primary energy consumption, while nuclear energy usage is much less, with about 32% and 7% respectively from the total energy consumption (EIA, 2012).

[20]In 2008, the government introduced New National Energy Strategy in light of global developments, which was heavily focused on achieving energy security. Under this strategy, the government targeted to improve energy efficiency to 30%, increase share of electric power generated from nuclear energy to 30-40%, cut down the oil dependency ratio to about 80% and increase domestic investment in oil exploration and related development projects (Sami, 2011).

technical change in France improves the real GDP by 0.11%.

The error-correction terms, α_1, shown in Table (9) are with the expected sign (negative) and highly significant for all the investigated countries, except for nuclear energy consumption equation in Japan. The magnitude of loading factors, α_1, show the speed of adjustment to disequilibrium from its long run equilibrium value. On this basis, it can be seen that when per capita real GDP deviates from its long-run trend, 28%, 5%, 35% and 32% of that deviation will be corrected within a year for the US, Canada, Japan, and France, respectively. Thus, the speed of adjustment in the case of any shock to the real GDP equation is sufficiently fast and support the notion that there is a reasonable control over economic growth, except for Canada.

Furthermore, bidirectional causality hypothesis in the long-run can be tested by the significance of the speed of adjustment, α, in Table (9). The t-statistics of the coefficients of the error correction term (ECT) is used to examine the existence of long-run causal effects. There is a strong evidence that there is a bi-directional causal linkage between oil price and economic growth in the US, which is in line with the finding of Hamilton (1983) and Hooker (1996) for the US, and Lee and Chiu (2011b) for heterogenous panel analysis. In Canada, results show that there is bidirectional causality between oil consumption and economic growth at 10% significance level, which is in line with Ghali and El-Sakka (2004). Oil prices, also, have feedback effect on Canadian real GDP growth in the long-run. These findings denote that an increase in Canadian economic growth may lead to increase the demands for oil in the long-run, and that the policies for reducing oil consumption may retard economic growth. Also, upsurge in international prices of oil may directly affect the level of economic growth in Canada. Alternatively, Japans' results suggest the existence of a bidirectional relationship between nuclear energy consumption and economic growth, suggesting that nuclear energy use derive economic growth, and that economic growth for Japan needs to use more nuclear power. Our finding of a bi-directional causality running between nuclear energy consumption and economic growth in Japan is not in line with the no causality found by Payne and Taylor (2010) for the US. The divergence of our results from Payne and Taylor (2010) may not only be due to the time period covered and the difference in the sources of the data, it may be differ as a result of the methodologies used in each analysis. Here, it is worth noting that Lee and Chiu (2011a) have found that an increase of 1% in Japanese income rises nuclear energy consumption by 1.436%. They argued that countries with higher income levels are more likely to have their basic needs and are concerned with environmental problems, as well as they have more money to invest in nuclear energy development. The speed of adjustment to disequilibrium is moderately high in France economic growth model, supporting long run causality running from oil consumption, nuclear energy consumption and real oil price to economic growth.

Hansen and Johansen (1999) propose a multivariate recursive procedure to evaluate the constancy of both the cointegration space and the loadings of the cointegration vector. Figure (2) shows the output of the former and consists of a graph where values over unity imply that there is a change in the cointegration space for a given cointegration rank. This test is performed using either **X** or its **R** representation. In the former, the recursive estimation is performed by re-estimating all parameters in the VECM, while in the later the dynamics are fixed and only the long run parameters are recursively estimated. Thus, the re-representation is more suitable when the constancy of the long run parameters are tested. The results support the existence of a stable long run relationship although there is some instability when the short and long run parameters are estimated for most of the cases.

Figure (3) presents the test for the stability of the adjustment coefficients of the VECM with asymptotic 95% error bounds. This test is performed once the cointegration space has been uniquely identified, and allows one to test whether the responses of the variables to of the variables to long-run disequilibrium are stable over time. The results suggest that the adjustment coefficients are stable.

6 Conclusion

To minimize the threats associated with international crude oil prices' shocks and oil supply shortages, the priority of energy policy for many countries has become diversifying the sources of energy, and finding a stable, safe, and clean energy supply. One such substitute, which fits these conditions, is nuclear energy. Therefore, one important emerging issue of energy consumption and economic development is "whether nuclear energy could replace oil and become an important factor for countries' industrialization in the future". Many studies in the existing literature may suffer from the omission variable bias. To improve any rise to this potential bias, in addition to real GDP this study also incorporates real oil price and oil consumption into our empirical analysis. The Johansen cointegration technique is applied to investigate the interrelationship among oil consumption, nuclear energy consumption, real oil price, and real economic growth in four industrialized countries (the US, Canada, Japan, and France) for the period 1965 - 2010.

Key results of this empirical analysis can be summarised in five folds. First, we find that a long-run relationship exists between economic growth and at least one energy source (oil or nuclear energy) in each country model, which implies that energy is an essential factor for production in all countries included in our sample. Second, results show that oil consumption enters significantly in the cointegration space of the US, Canada, and France. Third, findings reveal that nuclear energy consumption has a positive and significant impact on real GDP growth in both Japan and France. Fourth, in terms with causality, oil consumption has a predictive power for real GDP in the US, Japan, and France. In contrast, there is a bi-directional causality between oil consumption and economic growth in Canada. Finally, nuclear energy consumption has predictive power for real economic growth in the US, Canada, and France, while a bidirectional causal relationship between nuclear energy consumption and real GDP growth is exist in Japan, implying that energy conservation measures taken may negatively affect economic growth.

Our empirical findings have major policy implications, especially that results suggest that the investigated countries are highly dependent on energy consumption to stimulate economic growth. These findings reveal that high level of economic growth leads to a high level of energy demand and/or vice versa, which has a number of implications for policy analysts and forecasters. In order to deal with the lately concerns about the reliance on fossil fuels and not adversely affect economic growth, energy conservation policies that aim to curtailing energy use have to rather find ways of reducing demand on fossil fuel. Efforts must be made to encourage industries to adapt technology that minimise pollution. Alternatively, there is a keen interest in developing nuclear energy in many countries as a mean of ensuring energy security, reducing emissions, coping with the increase in energy demand all over the world, and stabilizing oil price. However, nuclear safety is a global concern that needs a global solution. The right balance should be struck between the quest of economic growth, nuclear safety, clean energy and the drive towards making these countries relatively energy independent.[21]

[21] Apergis et al. (2010) attempt to explore the causal relationship between CO_2 emissions, nuclear energy consumption, renewable energy consumption, and economic growth for 19 developed and developing countries. Their empirical results indicate that in the long-run, nuclear energy eliminates emission, a 1% increase in nuclear energy consumption is associated with with a 0.477% decrease in emission.

Table 1: **Descriptive Statistics**

Country	USA	Canada	Japan	France
Real Oil price mean	3.52	3.66	8.44	5.18
SD	0.67	0.68	0.27	0.66
Skewness	-0.24	-0.41	-2.35	0.07
Kurtosis	2.06	2.31	8.15	1.85
Normality	2.04	2.16	4.34	2.57
$p - value$	(0.36)	(0.34)	(0.11)	(0.28)
Oil consumption				
mean	9.75	7.47	8.44	7.55
SD	0.14	0.17	0.27	0.17
Skewness	-0.91	-0.49	-2.35	-1.49
Kurtosis	3.63	3.21	8.15	6.32
Normality	4.21	2.25	111.79	1.31
$p - value$	(0.11)	(0.33)	(0.00)	(0.09)
Nuclear energy consumption				
mean	5.57	3.60	4.14	4.56
SD	1.50	1.45	2.21	1.84
Skewness	-1.50	-1.05	-1.71	-0.95
Kurtosis	4.10	2.58	5.33	2.53
Normality	22.03	9.32	38.39	7.72
$p - value$	(0.08)	(0.01)	(0.00)	(0.02)
Real GDP				
mean	10.17	9.81	10.21	9.73
SD	0.27	0.24	0.35	0.26
Skewness	-0.09	-0.22	-0.79	-0.61
Kurtosis	1.75	2.07	2.66	2.41
Normality	3.10	1.96	5.20	3.59
$p - value$	(0.21)	(0.38)	(0.07)	(0.17)

Table 2: Tests of Unit Root

Country	Variable	ADF	lags	PP (4)	PP(8)	KPSS	lags
USA							
levels	OP	-1.70	(0)	-1.85	-1.96	0.13	(4)
	OC	-3.34	(1)	-2.75	-2.72	0.09	(4)
	NC	-3.45	(1)	-3.74*	-4.34**	0.23**	(4)
	Y	-3.20	(1)	-2.10	-1.82	0.10	(4)
first difference	OP	-6.57**	(0)	-6.80**	-6.81**	0.11	(4)
	OC	-4.17*	(1)	-3.61*	-3.85	0.10	(4)
	NC	-4.34**	(0)	-4.74**	-4.85**	0.16	(4)
	Y	-5.20**	(1)	-5.60**	-5.72**	0.08	(4)
Canada							
levels	OP	-1.84	(0)	-1.95	-2.05	0.13	(4)
	OC	-2.78	(1)	-2.66	-2.67	0.10	(4)
	NC	-0.71	(0)	-0.74	-0.68	0.25**	(4)
	Y	-2.48	(1)	-2.26	-2.03	0.13	(4)
first difference	OP	-7.11**	(0)	-5.46**	-5.92**	0.10	(4)
	OC	-3.75*	(0)	-0.63	-0.36	0.13	(4)
	NC	-6.28**	(1)	-1.95	-1.79	0.08	(4)
	Y	-5.01**	(0)	-0.94	-0.83	0.07	(4)
Japan							
levels	OP	-1.81	(0)	-1.93	-2.07	0.12	(4)
	OC	-2.15	(6)	-4.11*	-3.98*	0.16*	(4)
	NC	-3.16	(7)	-6.63*	-6.39**	0.25**	(4)
	Y	-3.26	(0)	-3.15	-3.17	0.24**	(4)
first difference	OP	-6.19**	(0)	-6.44**	-6.42**	0.10	(4)
	OC	-3.71*	(0)	-3.77*	-3.88*	0.14	(4)
	NC	-4.74**	(4)	-12.75**	-12.96**	0.20	(4)
	Y	-4.57**	(1)	-4.48**	-4.37**	0.09	(4)
France							
levels	OP	-1.65	(0)	-1.84	-1.94	0.15*	(4)
	OC	-3.99*	(1)	-3.59*	-3.54*	0.12	(4)
	NC	-1.55	(0)	-1.56	-1.59	0.11	(4)
	Y	-2.11	(1)	-2.01	-2.11	0.26**	(4)
first difference	OP	-6.29**	(0)	-6.52**	-6.52**	0.11	(4)
	OC	-3.73*	(0)	-3.89*	-3.98*	0.14	(4)
	NC	-1.97*	(2)	-5.74**	-5.67**	0.06	(4)
	Y	-4.99**	(0)	-5.10**	-5.03**	0.09	(4)

Notes: Table entries are the results obtained from unit root tests. Tests are shown in the first row: augmented Dickey and Fuller (1979) (ADF), Phillips and Perron (1988) (PP), and the stationarity test by Kwiatkowski et al. (1992) (KPSS). Regression include an intercept and trend. The variables are specified in the first column: oil price (OP), oil consumption (OC), nuclear energy consumption (NC) and real GDP (Y). All variables are in natural logarithms, while the lag length determined by Akaike Information Criteria and are in parentheses. '*' and '**' indicate significance at the 10% and 5% level, respectively. The nulls for all test except for the KPSS test are unit root.

Table 3: lag Selection Criteria

Country	K	AIC	HQIC	SBIC
USA	1	-11.67*	-11.37*	-10.84*
	2	-11.66	-11.11	-10.17
	3	-11.67	-10.88	-9.52
	4	-11.61	-10.58	-8.79
Canada	1	-9.81	-9.51*	-8.99*
	2	-9.65	-9.10	-8.16
	3	-9.88*	-9.10	-7.73
	4	-9.85	-8.82	-7.03
Japan	1	-8.63	-8.33	-7.80*
	2	-8.28	-7.74	-6.79
	3	-8.31	-7.52	-6.16
	4	-9.53*	-8.50*	-6.72
France	1	-10.75*	-10.45*	-9.92*
	2	-10.49	-9.95	-9.01
	3	-10.34	-9.55	-8.19
	4	-10.72	-9.69	-7.90

Notes: AIC, HQIC and SBIC stand for Akaike, Hannan and Quinn and Schwarz's Bayesian information criteria, respectively. In the case of conflicting results, we use AIC results as suggested by Pesaran and Pesaran (1997). '*' indicates significant at 5% level.

Table 4: Multivariate Misspecification Tests

Country	Test	Test statistics
USA		
	LM (1)	$\chi^2(16)$=17.18 (0.37)
	LM (2)	$\chi^2(16)$=14.54 (0.55)
	Normality	$\chi^2(8)$= 13.21 (0.10)
Canada		
	LM (1)	$\chi^2(16)$=17.18 (0.37)
	LM (2)	$\chi^2(16)$=16.44 (0.42)
	Normality	$\chi^2(8)$= 4.69 (0.79)
Japan		
	LM (1)	$\chi^2(16)$=17.18 (0.37)
	LM (2)	$\chi^2(16)$=22.75 (0.12)
	Normality	$\chi^2(8)$= 14.04 (0.08)
France		
	LM (1)	$\chi^2(16)$=17.18 (0.37)
	LM (2)	$\chi^2(16)$= 22.14 (0.13)
	Normality	$\chi^2(8)$= 11.79 (0.16)

Notes: $p-values$ are given in parentheses. Lagrange-multiplier (LM): H_0: No autocorrelation at lag order. Normality: H_0: Disturbances are normally distributed.

Table 5: **Johansen's Cointegration Test**

Country	H_0	H_1	λ_{max}	**Trace***	**95% c.v**	**P-Value***
USA	$r = 0$	4	0.783	76.347	63.659	0.002***
	$r \leq 1$	3	0.495	34.703	42.770	0.261
	$r \leq 2$	2	0.396	20.706	25.731	0.195
	$r \leq 3$	1	0.216	6.987	12.448	0.356
Canada	$r = 0$	4	0.596	51.751	53.945	0.079*
	$r \leq 1$	3	0.452	28.681	35.070	0.215
	$r \leq 2$	2	0.295	7.614	20.164	0.850
	$r \leq 3$	1	0.078	1.796	9.142	0.811
Japan	$r = 0$	4	0.572	68.773	63.659	0.017**
	$r \leq 1$	3	0.465	39.232	42.770	0.111
	$r \leq 2$	2	0.365	19.752	25.731	0.243
	$r \leq 3$	1	0.250	7.554	12.448	0.299
France	$r = 0$	4	0.455	68.158	63.659	0.048**
	$r \leq 1$	3	0.398	27.715	42.770	0.643
	$r \leq 2$	2	0.281	17.022	25.731	0.421
	$r \leq 3$	1	0.207	7.649	12.448	0.290

Notes: The entries of the upper row show the name of the country in the first column, followed by the null hypothesis H_0, that tests for a cointegration rank of r, then H_1 shows the alternative. λ_{max} shown in the fourth column represents the maximum eigenvalue statistics, $Trace*$ shows the trace statics, $95\% c.v$ represents the critical values at 5% level, and finally $p - values$ are provided in the last column. '*', '**', and '***' indicate significance at the 10%, 5% and 1% level, respectively.

Table 6: Un-restricted Long-run Relationship using Johansen's Cointegration Technique

Country		β_1		α_1
USA	OC	-0.786***	Δ GDP	-0.224***
		(-5.200)		(-3.745)
	NC	-0.015	Δ OC	0.060
		(-1.203)		(0.679)
	ROP	0.007	Δ NC	0.704**
		(0.380)		(2.026)
	T	-0.012***	Δ ROP	-2.998***
		(-8.882)		(-2.969)
Canada	OC	-2.433***	Δ GDP	-0.092***
		(-12.012)		(-3.144)
	NC	-0.023	Δ OC	-0.065
		(-1.035)		(-1.442)
	ROP	0.357***	Δ NC	-0.288
		(7.621)		(-1.084)
			Δ ROP	-1.766***
	Constant	7.091***		(-5.620)
		(5.222)		
Japan	OC	0.101	Δ GDP	-0.261***
		(1.427)		(-3.638)
	NC	-0.123***	Δ OC	0.156
		(-10.413)		(1.158)
	ROP	0.009	Δ NC	2.510***
		(0.592)		(3.451)
	T	-0.011***	Δ ROP	0.024
		(-9.351)		(0.022)
France	OC	-0.249***	Δ GDP	-0.238***
		(-7.656)		(-2.588)
	NC	-0.039***	Δ OC	-0.279
		(-5.402)		(-0.987)
	ROP	0.038***	Δ NC	3.382***
		(3.898)		(4.295)
	T	-0.015***	Δ ROP	-4.847***
		(-15.891)		(-2.438)

Notes: Table entries are the estimates of the un-restricted long-run relationship using Johansen's Cointegration Technique. The long-run relationship has been normalized on the economic growth (GDP). The variables in the first column are: oil consumption (OC), nuclear energy consumption (NC) and real oil price (ROP). β_1 represents the estimated long-run parameters and α_1 shows the speed of adjustment in each equation. Numbers in parentheses are t-statistics where ***, ** and * denote significance at the 1%, 5% and 10% respectively.

Table 7: Variables Exclusion Test

Country	Variable	LR test	$p - value$
USA	GDP	3.824**	0.050
	OC	10.136***	0.001
	NC	0.943	0.332
	ROP	0.084	0.772
	T	1.537**	0.025
Canada	GDP	5.157**	0.023
	OC	11.946***	0.001
	NC	0.276	0.599
	ROP	12.184***	0.000
	Constant	9.485***	0.002
Japan	GDP	6.729***	0.009
	OC	0.457	0.499
	NC	6.790***	0.009
	ROP	0.072	0.788
	T	4.931**	0.026
France	GDP	11.108***	0.001
	OC	6.070**	0.014
	NC	8.093***	0.004
	ROP	0.754	0.385
	T	7.265***	0.007

Notes: Table entries in the second column show the name of the variable tested for exclusion from the cointegration relationship including: economic growth (GDP), oil consumption (OC), nuclear energy consumption (NC) and real oil price (ROP). Tests are on the null hypothesis that the particular variable listed is not in the cointegration space. The test is constructed by re-estimating VECM model which which cointegration coefficient β in Equation (3) for corresponding variable is restricted to zero. Under the null hypothesis, the test statistics is distributed chi-squared with one degree o freedom. '***', '**' and '*' relates to the decision to reject the null hypothesis at 1%, 5% and 10% significant level, respectively.

Table 8: Variables Exogeneity Test

Country	**Variable**	**LR test**	$p - value$
USA	GDP	8.094*	0.004
	OC	0.361	0.548
	NC	3.155	0.076
	ROP	4.366*	0.037
Canada	GDP	5.154*	0.023
	OC	1.424*	0.033
	NC	0.692	0.406
	ROP	10.091*	0.001
Japan	GDP	4.060*	0.044
	OC	0.366	0.545
	NC	5.970*	0.015
	ROP	0.000	0.987
France	GDP	3.903*	0.048
	OC	0.248	0.618
	NC	3.708*	0.054
	ROP	1.170	0.279

Notes: Table entries in the second column show the name of the variable tested for weak exogeneity including: economic growth (GDP), oil consumption (OC), nuclear energy consumption (NC) and real oil price (ROP). Tests are on the null hypothesis that the particular variable listed is not responsive to deviation from previous period cointegration relationship. That is the variable's speed of adjustment α in Equation (4) is zero. Under the null hypothesis, the test statistics is distributed chi-squared with one degree o freedom. '***', '**' and '*' relates to the decision to reject the null hypothesis at 1%, 5% and 10% significant level, respectively.

Table 9: Restricted Long-run Relationship using Johansen's Cointegration Technique

Country		β_1		α_1
USA	restricted model test $\chi^2(4)$=4.515 [0.704]			
	OC	-0.759	Δ GDP	-0.283
		(-6.255)		(-4.770)
	NC	0	Δ OC	0.000
		(0.000)		(0.000)
	ROP	0	Δ NC	0.000
		(0.000)		(0.000)
	T	-0.012	Δ ROP	-2.238
		(-9.187)		(-1.992)
Canada	restricted model test $\chi^2(2)$= 0.749 [0.688]			
	OC	-3.078	Δ GDP	-0.053
		(-13.568)		(-2.433)
	NC	0.000	Δ OC	-0.053
				(-1.652)
	ROP	0.499	Δ NC	0.000
		(7.501)		
			Δ ROP	-1.355
	C	11.319		(-6.341)
		(7.494)		
Japan	restricted model test $\chi^2(4)$= 3.782 [0.436]			
	OC	0.000	Δ GDP	-0.353
				(-4.823)
	NC	-0.108	Δ OC	0.000
		(-13.265)		
	ROP	0.000	Δ NC	2.662
				(3.289)
	T	-0.012	Δ ROP	0.000
	(-12.701)			
France	restricted model test $\chi^2(4)$=8.446 [0.077]			
	OC	-0.262	Δ GDP	-0.320
		(-6.183)		(-2.862)
	NC	-0.049	Δ OC	0.000
		(-5.363)		
	ROP	0.000	Δ NC	0.000
	T	-0.011	Δ ROP	0.000
		(-9.452)		

Notes: Notes: Table entries are the estimates of the un-restricted long-run relationship using Johansen's Cointegration Technique. The long-run relationship has been normalized on the economic growth (GDP). The variables in the first column are: oil consumption (OC), nuclear energy consumption (NC) and real oil price (ROP). β_1 represents the estimated long-run parameters and α_1 shows the speed of adjustment in each equation. Numbers in parentheses are t-statistics where ***, ** and * denote significance at the 1%, 5% and 10% respectively.

Figure 1: Country Data

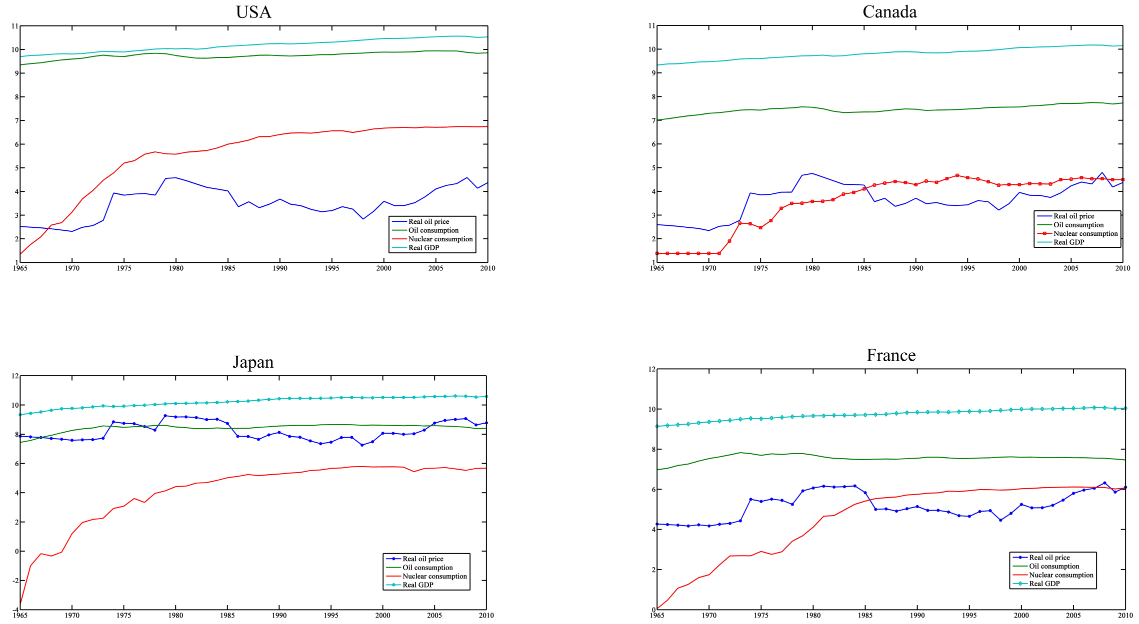


Figure 2: Hansen and Johansen (1999) test of constancy of $\hat{\beta}$

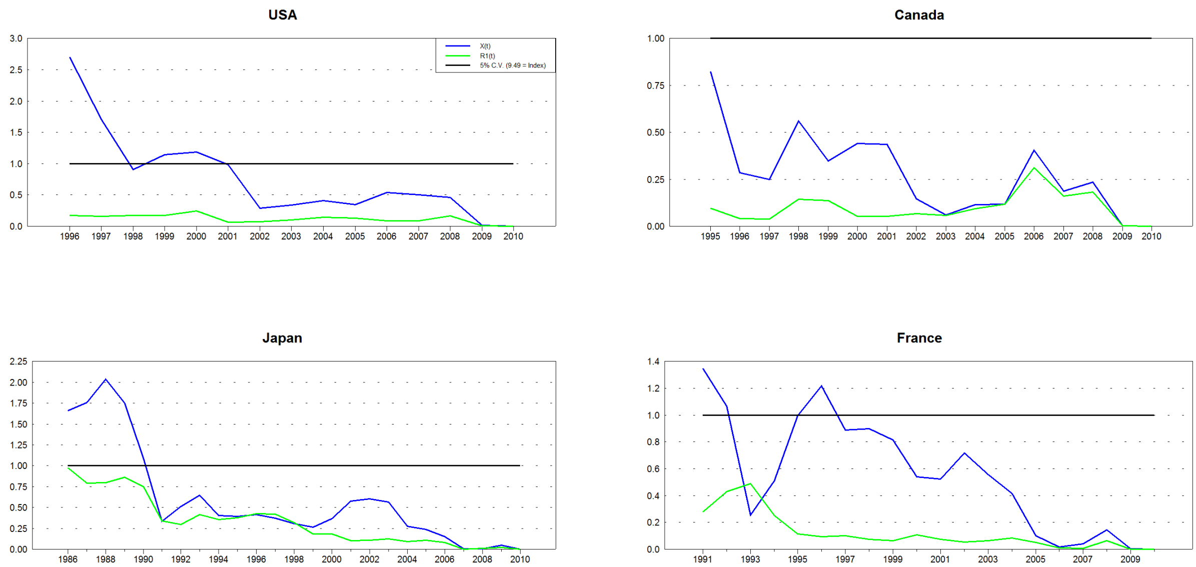
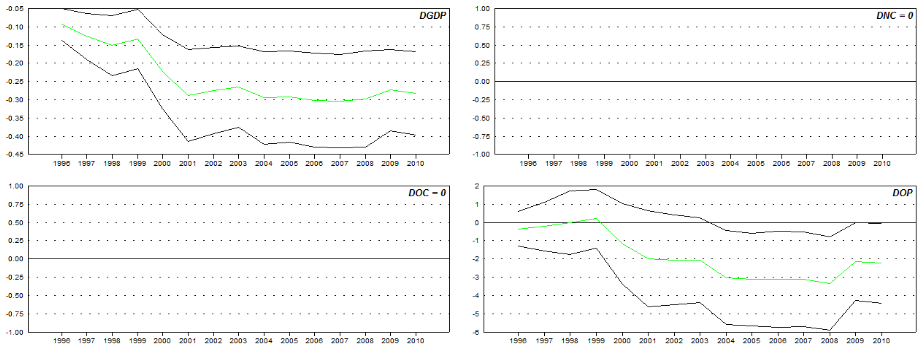
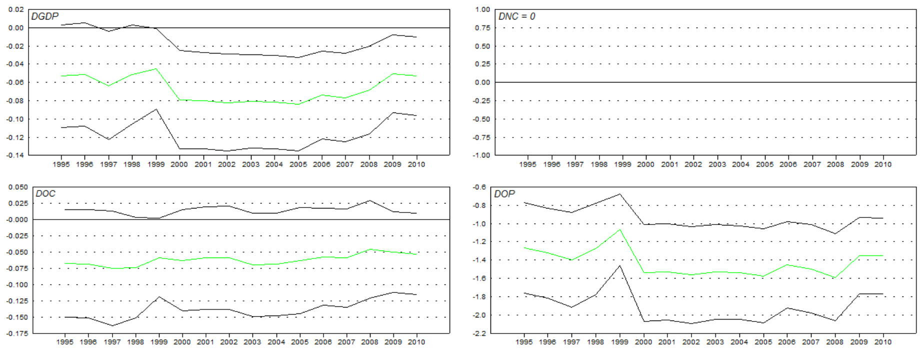


Figure 3: Hansen and Johansen (1999) test of constancy of $\hat{\alpha}$

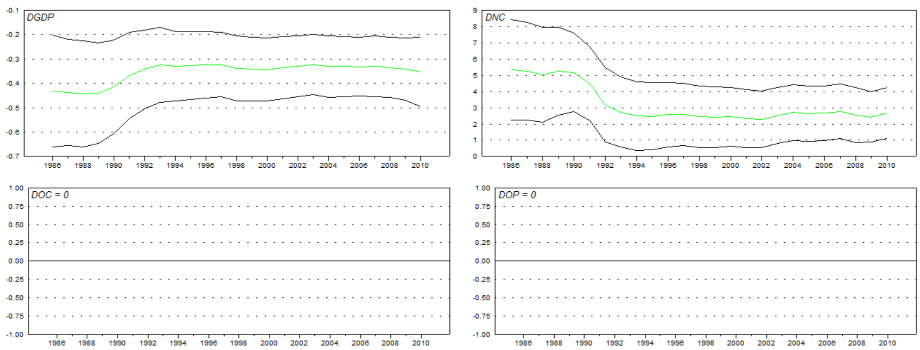
USA



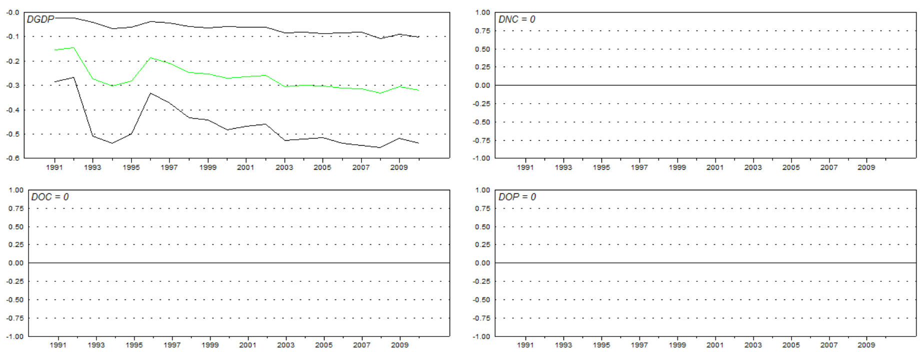
Canada



Japan



France



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